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Thermal Fatigue of Cast and Hot-Pressed Lead-Antimony-Silver-Tellurium (LAST) Thermoelectric Materials

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Lead-antimony-silver-tellurium (LAST) thermoelectric materials are candidates for waste-heat recovery applications. However, rapid heating and cooling (thermal shock) imposes thermomechanical stresses that can cause microcracking. Waste-heat recovery applications involve thermal fatigue, in which a series of hundreds or thousands of individual thermal shock events can lead to accumulation of microcrack damage in brittle thermoelectrics such as LAST. Microcracking in turn leads to a decrease in transport properties, such as electrical conductivity and thermal conductivity, and mechanical properties, including elastic modulus and strength. Thus, microcracking can affect both thermoelectric performance and mechanical integrity. In this study, LAST specimens were rapidly cooled (quenched) into a fluid (water or silicone oil) in order to compare the results with the vast majority of thermal shock studies of brittle materials that are quenched in a similar manner. Decreases in elastic modulus, E, with accumulating microcrack damage were measured using resonant ultrasound spectroscopy (RUS). The evolution of thermal fatigue damage observed in this study is also described well by an equation that successfully describes thermal fatigue damage in a variety of brittle materials.

Key words: Thermoelectrics, thermal fatigue, Young's modulus, waste-heat recovery

INTRODUCTION

An important application of thermoelectric materials is that of direct conversion of waste heat into useful electricity.[1] The efficiency of conversion is governed by the dimensionless figure of merit, ZT, where

$$ZT = S^2 \sigma_e T/\kappa \tag{1}$$

and S is the Seebeck coefficient, σ_e is the electrical conductivity, and κ is the thermal conductivity. To be a viable candidate for waste-heat recovery applications, a thermoelectric must have $ZT > 1$. LAST refers to a family of lead-antimony-silver-tellurium thermoelectric compounds that have ZT values as high as 1.7 at 700 K.[2,3] Nanostructures within LAST scatter phonons, which in turn decreases κ,[3–5] thus increasing ZT (Eq. 1). In addition, the coherent interfaces between the matrix and nanostructures in LAST[3,4] reduce electrical conductivity losses due to interfacial scattering,[5] thus enhancing ZT (Eq. 1).[3–5] The relatively high ZT values for LAST result in high energy conversion, making LAST a viable candidate for thermoelectric modules used in waste-heat conversion.[2,3]

Nevertheless, the cold start-ups and hot shutdowns that are inevitable in waste-heat recovery operations require that thermoelectric materials also have sufficient mechanical integrity to survive stresses imposed by thermal cycling. The maximum surface thermal stress, $\sigma_{\mathrm{TH}}\max$, experienced by a flat plate exposed to thermal transient conditions may be written as[6,7]

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